The MONITOR

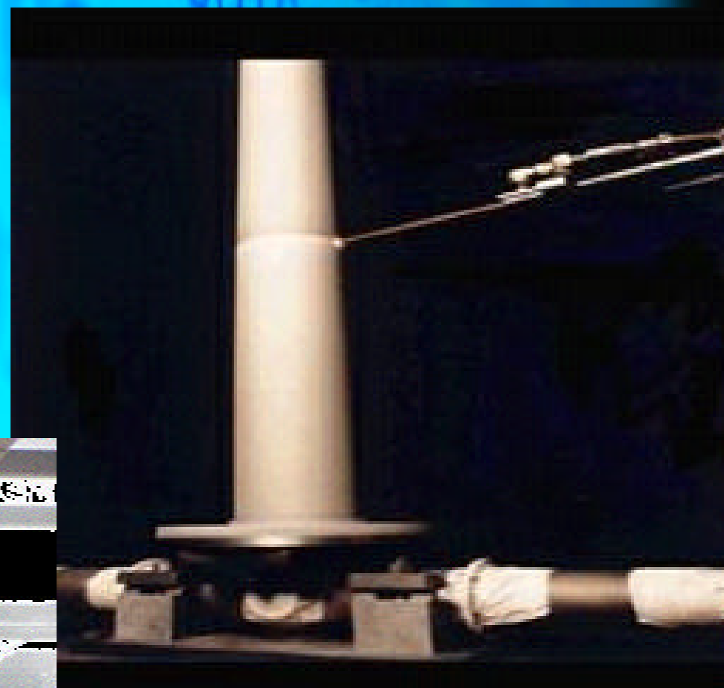
Aeronautical Systems Center (ASC/ENVV)

Vol. 8, No. 8, Winter 2004/AFMC Public Release Number 0104

Bldg 8 · 1801 Tenth St · Suite 2 · WPAFB, OH 45433-7626 · Commercial: (937) 255-3566 · DSN: 785-3566 · Fax: (937) 255-4155

Success Stories:

AFMC Pollution Prevention Integrated Product Team's Top Funded Technologies



High Velocity Oxygen Fuel (HVOF)*

Powder Coatings

Handheld Lasers

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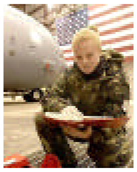

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The MONITOR is a quarterly publication of the Headquarters Air Force Materiel Command (AFMC) Pollution Prevention Integrated Product Team (P2IPT) dedicated to integrating environment, safety, and health related issues across the entire life cycle of Air Force Weapon Systems. AFMC does not endorse the products featured in this magazine. The views and opinions expressed in this publication are not necessarily those of AFMC. All inquiries or submissions to the MONITOR may be addressed to the Program Manager, Mr. Frank Brown.

Aeronautical Systems Center (ASC/ENVV)
Bldg. 8 • 1801 Tenth Street • Suite 2 •
Wright-Patterson AFB, OH 45433-7626
Commercial: (937) 255-3566
DSN: 785-3566
FAX: (937) 255-4155

Regulations and Information Cross-Feed

Regulations That Impact Air Force Industrial Processes and Weapon Systems

Aeronautical Systems Center, Weapon System Pollution Prevention Branch (ASC/ENVV) is tracking several emerging stringent federal and California state regulations that may impact Air Force industrial process and weapon systems. These regulations are tracked to formulate pollution prevention strategies that mitigate the potential cost and liability associated with compliance. Additionally, regulations with upcoming defined deadlines are tracked in order to ensure ASC weapon system and government owned contractor operated (GOCO) pollution prevention projects incorporate the pending cost and liability of these regulations in the prioritization of its high risk drivers. Details associated with some of key upcoming federal and state regulations being tracked by this processes are further discussed below.

2003 Regulator Driver Deadline

Regulatory Driver: Eliminate/minimize the use of HCFC-141b by January 1, 2003.

In December 1993, the Environmental Protection Agency (EPA) promulgated a final rule under Section 606 of the Clean Air Act that identified the accelerated phase-out schedule for Class I and Class II ODS. As of January 1, 2003, EPA has banned the production and importing of HCFC-141b. Many Air Force Materiel Command (AFMC) organizations have on-going or completed projects to help eliminate the use of HCFC-141b for cleaning electronics/ avionics and aircraft oxygen system components. Known pollution prevention projects that have been or are being proposed for implementation to address this compliance driver include the following:

- PEWG – Hot Engine Leak Test (ZHTV00PV29);
- JG-PP – Non ODS O2 Line Cleaning (J-99-Cl-015);
- AFRL/MLSC – HCFC-141b Replacements (ZHTV01W144);
- WR-ALC – Eliminate HCFC 141b Use (UHHZ020029);
- ASC/ENVV – Non ODS O2 Line Cleaning System Field Qualification (AFMC05PV02);
- Elimination of CFC-113 Wipe Cleaning of Oxygen Components (ZHTV00PV31, ZHTV01PV31, ZHTV02PV31).

The solution that has been successfully transitioned to address this driver includes De-ionized water and HFE/HFC mixture for the PEWG Hot Engine Leak Test project (see Fall 2003 issue of the MONITOR for more details).

As of January 1, 2003, EPA has banned the production and importing of HCFC-141b.

2005 Regulatory Driver Deadline

Reduce the VOC content of Adhesion Promoters from 850 g/l to 250 g/l by January 1, 2005. (California SCAQMD Rule 1124)

This rule applies to any operation associated with manufacturing and assembling products for aircraft and space vehicles for which an aerospace material is used. The affected industries include commercial and military aircraft, satellite, space shuttle and rocket manufacturers and their subcontractors. This rule also applies to maskant applicators, aircraft refinishers, aircraft fastener manufacturers, aircraft operators, and aircraft maintenance and service facilities. Under this rule, effective January 1, 2005, a person shall not apply any adhesion promoters, including any VOC-containing materials added to the original material supplied by the manufacturer, to aerospace components, which contain VOC in excess of 250 g/l. The current limit is 850 g/l. The reduction of VOC content in adhesion promoters has been identified as a need at most of AFMC's GOCO facilities and at Edwards AFB.

Effective January 1, 2005, a person shall not apply any adhesion promoters, including any VOC-containing materials added to the original material supplied by the manufacturer, to aerospace components, which contain VOC in excess of 250 g/l.

Known pollution prevention projects that have been or are being implemented to address this compliance driver include the following:

- F-16 - Alternatives to High VOC Coatings (CPP 10522, Task 5);
- AFP42 - Alternatives to Freekote 400-NC (Internally Funded);
- HQ AFMC/LGPE – Evaluate Wipe Solvent Adhesive Promoter for Surface Prep (AFMC03G531).

Reduce VOC content in cleaning solvents used for screen printing applications from 750 g/l to 100 g/l by July 1, 2005. (California SCAQMD Rule 1171)

This rule applies to the use VOC-containing materials in solvent cleaning operations during the production, repair, maintenance, or servicing of parts, products, tools, machinery, equipment, or general work areas, and to the storage and disposal of VOC-containing materials used in solvent cleaning operations. The rule exempts cleaning operations subject to Rule 1124 (Aerospace Assembly and Component Manufacturing Operations) with the specific exception of coating application equipment cleaning, and storage and disposal of VOC-containing materials used in solvent cleaning operations. Under this rule, a solvent used to perform cleaning of ink application equipment used in screen printing should not exceed a VOC content of 100 g/l by July 1, 2005. The current limit is 750 g/l.

A solvent used to perform cleaning of ink application equipment used in screen printing should not exceed a VOC content of 100 g/l by July 1, 2005.

Reduce VOC content for solvents used in cleaning of equipment for ink applications from 50 g/l to 25 g/l by July 1, 2005. (California SCAQMD Rule 1171)

Under this rule, any solvent used to clean ink application equipment must meet the VOC limit of 25 g/l by July 1, 2005. The current limit is 50 g/l.

Implement an EMS by 2005. (Executive Order 13148)

By order of the President under Executive Order (EO) 13148, the head of each Federal Agency is responsible for ensuring that all necessary actions are taken to integrate environmental accountability into agency day-to-day decision-making and long-term planning processes, across all agency missions, activities, and functions. Environmental management considerations must become a fundamental and integral component of Federal Government policies, operations, planning, and management. In order to promote environmental management and leadership, Section 410 (b) of EO13148 requires each agency to implement an environmental management system at all appropriate agency facilities based on facility size, complexity, and the environmental aspects of facility operations by December 31, 2005. The facility environmental management system shall include measurable environmental goals, objectives, and targets that are viewed and updated annually. Once established, environmental management system performance measures shall be incorporated in agency facility audit protocols

EO13148 requires each agency to implement an environmental management system at all appropriate agency facilities based on facility size, complexity, and the environmental aspects of facility operations by December 31, 2005.

Known pollution prevention projects that have been or are being implemented to address this compliance driver includes the ASC/ENVV EOHMS Development.

Reduce industrial process energy used by 20% by 2005 and 25% by 2010. (Executive Order 13123)

EO 13123 requires the Federal Government to significantly improve its energy management to reduce cost and the associated emissions that contribute to air pollution and global climate change. The goals for industrial and laboratory facilities are described in Section 203 of EO 13123. Through life-cycle cost-effective measures, each agency is required to reduce energy consumption per square foot, per unit of production, or per unit as applicable by 20% by 2005 and 25% by 2010 relative to 1990. All facilities are required to meet these goals, unless they meet new criteria for exemptions issued by the Department of Energy (DOE).

Each agency is required to reduce energy consumption per square foot, per unit of production, or per unit as applicable by 20% by 2005 and 25% by 2010 relative to 1990.

2006 Deadline (Anticipated)

Reduce TRI emissions at facilities by 40% by December 31, 2006 from the 2001 baseline. (EO 13148 Section 502)

Each agency is required to establish a goal of reducing, where cost effective, the agency's total releases of toxic chemicals to the environment and off-site transfers of such chemicals for treatment and disposal by at least 10% annually, or by 40% overall by December 31, 2006. Beginning with activities for calendar year 2001, the baseline for measuring progress in meeting the reduction goal will be the aggregate of all such releases and off-site transfers as reported by all of the agency's facilities under Section 501 of the Order. The list of toxic chemicals applicable to this goal is the EPCRA Section 313 list dated December 1, 2000. If an agency achieves the 40% reduction goal prior to December 31, 2006, that agency shall establish a new baseline and reduction goal based on agency priorities.

Each agency is required to establish a goal of reducing, where cost effective, the agency's total releases of toxic chemicals to the environment and off-site transfers of such chemicals for treatment and disposal by at least 10% annually, or by 40% overall by December 31, 2006.

Known pollution prevention projects that have been or are being implemented to address this compliance driver include the following:

- PEWG – Dry Film Lubricant (DFL) for Engines (ZHTC96136, ZHTV960V36);
- AFFTC – AGE Powder Coating Implementation (ASPM024017);
- OC-ALC – Dem/Val Powder Coatings on Non-Flight Critical Aerospace Components (WWYK-011006, WWYK-021006);
- WR-ALC – Dem/Val Powder Coating Booth (ZHTV00CP98);
- HQ AFMC/LGPE – Evaluate DFL for Non-engine purposes (AFMC03G532);
- HQ AFMC/LGPE - Demonstrate Powder Coatings Technology (ZHTV01G506);
- ASC/ENVC – Elimination of VOCs and HAPs and AFP44 (ACHA98PV21, ACHA99PV21, ACHA01PV21);
- AFP44-VOC Elimination Powder Coating Follow On (ACHA01PV07, ACHA02PV07, ACHA03PV07).

The solutions that are being investigated are Tiolube 614-T9B, Everlube 812 and Everlube 10030 for the PEWG DFL project (see page 17).

Reduce the use of selected toxic chemicals, hazardous substances, and pollutants or generation of hazardous and radioactive waste streams 50% by December 31, 2006. (EO 13148 Section 503)

Through identification of proven substitutes and established facility management practices, including pollution prevention, each agency is required to reduce its use of selected toxic chemicals, hazardous substances, and pollutants, or its generation of hazardous and radioactive waste types at its facilities by 50% by December 31, 2006. The baseline for measuring reductions to achieve the 50% reduction goal is the first calendar year following the

Each agency is required to reduce its use of selected toxic chemicals, hazardous substances, and pollutants, or its generation of hazardous and radioactive waste types at its facilities by 50% by December 31, 2006.

development of the list of priority chemicals for the facility. If an agency is unable to meet the 50% reduction goal, that agency will reduce the use of selected hazardous substances or its generation of other pollutants at its facilities by 50% by December 31, 2006.

Meet the non-enforceable MCLG of zero and a MCL (enforceable) of 0.01 mg/l for arsenic by 23 January 06. (SDWA 40CFR Parts 141 and 142)

EPA revised the standard for concentrations of arsenic in drinking water in a Final Rule that was promulgated on January 22, 2001. Both community water systems (CWSs) and non-transiet, non-community water systems (NTNCWSs) will be required to reduce the arsenic concentration in their drinking water systems to 0.010 mg/l. A CWS is a public water system that serves at least 15 locations or 25 residents regularly year round (e.g., most cities and towns, apartments, and mobile home parks with their own water supplies). An NTNCWS is a public water system that is not a CWS and serves at least 25 of the same people more than 6 months of the year (e.g., schools, churches, nursing homes, and factories).

All CWSs and all NTNCWSs that exceed the MCL of 0.010 mg/L will be required to come into compliance 5 years after the publication of the final rule (published on January 22, 2001).

All CWSs and all NTNCWSs that exceed the MCL of 0.010 mg/L will be required to come into compliance 5 years after the publication of the final rule (published on January 22, 2001). Beginning with reports that are due by July 1, 2002, all CWSs will begin providing health information and arsenic concentrations in their annual consumer confidence report (CCR) for water that exceeds ½ the new MCL.

2007 DEADLINE (ANTICIPATED)

Reduce the worker exposure to chromium from 100 mg/m^3 to 0.5 mg/m^3 by 2007. (OSHA 29CFR 1910)

In 1993, OSHA was petitioned to promulgate an emergency temporary standard (ETS) to lower the permissible exposure limit (PEL) for hexavalent

The proposed rule (OSHA or standard) is set for October 2004, with the final rule January 2006, compliance estimated to be set for January 2007.

chromium to 0.5 microgram per cubic meter as an 8-hr time-weighted average (TWA). On December 4, 2002 OSHA announced its plans to go forward with proposed rule making on occupational exposure to hexavalent chromium. Hexavalent chromium is most commonly as structural and anti-corrosive element in the production of stainless steel, iron. And steel, as well as electroplating, welding, and painting. The proposed rule (OSHA or standard) is set for October 2004, with the final rule January 2006, compliance estimated to be set for January 2007. This regulatory driver is the major driver for current focus on chromium reduction in weapon system pollution prevention drivers. When implemented, the reduced PEL can pose a significant mission impact and cost to the AF.

Known pollution prevention projects that have been or are being implemented to address this compliance driver include the following:

- JG-PP – Chrome Free Primer for Inserts and Fasteners (J-95-MF-003);
- JG-PP – Boeing Aircraft and Missile Non Chromate Primer for Aircraft Outer Mold Line (ZHTV02G002);
- JG-PP – Chrome Free Conversion Coating (J-95-OC-001);
- JG-PP – Dem/Val Non-Chrome Aluminum Pretreatments/Primers Phase 1 (AFMC03G543);
- JG-PP – Replacement of Hard Chrome Plating on Hydraulic Actuators (J-00-MF-020);
- JG-PP – Replacement of Hard Chrome Plating on Landing Gear (S-98-MF-012, ZHTV002030);
- JG-PP – Replacement of Hard Chrome Plating on Propeller Hubs (S-98-MF-012, ZHTV002032);
- JG-PP – Low/No VOC and nonchromated Coating System for Support Equipment (J-99-OC-014);
- ASC/ENVV – AFP6 Non-Chromated Primer for C-130 OML (ADFL03PV03);
- ASC/ENVV – Qualify Laser Cladding to Eliminate Chrome Plating – I (AFMC04PV43);
- ASC-ENVV – Non-Chromated Fuel Tank Coating (AMS-C-27725);
- HQ AFMC/LGPE – Test a Non-Chromated Primer for Use with Interior of USAF Aircraft (ZHTV02G514);
- OO-ALC – Non-Chromate Conversion Coating (KRSM000908);
- OO-ALC - Replace Chromic Acid Anodize Strip Solutions (KRMS000906);
- AFRL/MLSC – Non-Chromate Conversion Coating (ZHTV02W153);
- AFRL/MLSC – Low & No VOC Corrosion Preventive Coatings for Space & Missile Facilities (ZHTV02W145);
- AFRL/MLBT – Transitions from Chromates to Chromate Free Corrosion Protection (PP-1119);
- PEWG – Validation of Advanced Thermal Spray Coatings – HVOF (ZHTV99PV38, ZHTV00PV38, ZTHV01PV38, ZTHV03PV38);
- AFRL/MLSC - Electrospark Deposition Depot Implementation (ZHTV02P01);
- AFRL/MLSC - Qualify SermeTel W Alternative (ZHTV01LP32);
- WR-ALC – Replacement of Chromic Acid Anodize (UHHZO11321);

- AFRL/MLSC – High Temp HVOF (ZHTV01W131, ZHTV02W131);
- AFRL/MLSC - Heavy Metal Alt Internal Surface (non-line of sight Chrome Alternatives) (ZTHV99WL44, ZHTV00WL44);
- AFRL/MLSC - Evaluate Advanced Non-Line of Hard Chrome Alternatives (AFRL03W143A1);
- AFRL/MLSC - NDI Inspection through Thermal Spray Coatings (ZHTV00W130, ZHTV01W130);
- OC-ALC/EM – HVOF Implementation (KRSM000934);
- OC-ALC/EM - Dem/Val ESD Process for replacing brush plating (KRSM782881);
- OC-ALC/EMC – Dem/Val Electrospark Deposition (KRSM782969);
- AFRL/MLS-OLR – Test and Demonstrate Metal Wire Arc Spray (MWAS) Materials on Rocket Launch Tower (ZHTV02CP02);
- AFRL/MLS-OLR - Cadmium as Replacement for CARC (ZHTV01CP87, ZHTV02CP87).

For ASC SPO specific projects related to this compliance driver, please contact Mr. Frank Brown directly.

The solutions that are being investigated and/or have been successfully transitioned to address this driver include the following: TT-P-645B Zinc Molybdate Primer, TT-P-664D High Solids Primer for JG-PP project J-95-MF-003, HVOF for multiple projects as well as Electrospark Deposition (ESD).

Potentially reduce the occupational exposure to beryllium further from the initially proposed 1 mg/m^3 to 0.2 mg/m^3 TWA. (OSHA 29CFR 1910)

In 1977, OSHA proposed to reduce the 8-hour TWA exposure to beryllium from 2 μg/m^3 to 1 μg/m^3 based on evidence that beryllium caused lung cancer in exposed workers. A hearing followed the proposal, but a final standard was never published. Since the previous OSHA hearing, NIOSH has updated its studies on beryllium exposed workers. The study results again demonstrated a significant excess of lung cancer among exposed workers. The International Agency for Research on Cancer (IARC) has concluded that beryllium is a carcinogen in humans (Category I).

> *Based on several recent studies involving workers employed in the beryllium ceramics industry, in beryllium production, and in Department of Energy facilities, there is now evidence that very low level beryllium exposure (less than 0.5 ug/m^3) may cause CBD.*

Based on several recent studies involving workers employed in the beryllium ceramics industry, in beryllium production, and in Department of Energy facilities, there is now evidence that very low level beryllium exposure (less than 0.5 ug/m^3) may cause Chronic Beryllium Disease (CBD). OSHA was petitioned to issue an emergency temporary standard (ETS) by the Paper, Allied-Industrial, Chemical and Energy Workers Union (PACE) to protect workers from developing CBD and lung cancer as a result of occupational beryllium exposure. The petition was denied, but the Agency has initiated rulemaking under section 6(b)(5) to protect beryllium-exposed workers from contracting these diseases. OSHA's current permissible exposure limits for beryllium are: an 8-

hour TWA of 2 $\mu g/m^3$; a 5 $\mu g/m^3$ ceiling concentration not to be exceeded over a 30-minute period; and a 25 $\mu g/m^3$ maximum peak exposure never to be exceeded.

Known pollution prevention projects that have been or are being implemented to address this compliance driver include the following:

- ASC/ENVV – Alternative to Copper Beryllium (ACFJ05PV37);
- ASC/ENVV - HAZMAT Reduction – Beryllium and Cadmium (ACHA05PV02).

If you have any on-going projects that address these regulatory drivers and you would like to cross-feed your information with AFMC, please contact Frank Brown at DSN 785-3526 or Frank.Brown@wpafb.af.mil.

Aging System Containment and Enabling Technologies (ASSET)

Website: **http://www.asset.okstate.edu**

Description: ASSET is a National Reinvention Laboratory initiated in 1994 by Oklahoma State University to address Department of Defense (DoD) procurement problems. ASSET is a government-academic-business partnership. Current principal partners include the Defense Logistics Agency, Oklahoma City Air Logistics Center, Oklahoma State University, Archer Technologies International Inc., Knowledge Base Engineering, Mercer Engineering Research Center and Sverdrup Technologies Inc. ASSET technology development and insertion activities have created manufacturers' capabilities and grouped parts databases, parts-demand forecasting models, new materials technologies for ceramic bearings, new processes for reducing corrosion of aging systems, and new training materials. The technologies and processes developed in the ASSET program increase the DoD supply base, reduce the time and costs associated with parts procurement, and enhance military readiness.

Ongoing Projects: Ongoing projects of use to the pollution prevention community include following:

- *Organic-Inorganic Hybrid Coatings for Corrosion Protection of Aerospace Aluminum Alloys* **-** The ASSET program is performing research in sol-gel-derived hybrid coatings on aircraft aluminum alloys to improve corrosion resistance and replace old chromate-based paint applications. Complete paint systems for military aircraft are three-layer systems composed of a passivating base layer (generally Alodine), an inhibitor-containing primer layer, and a colored topcoat. Research efforts have shown that sol-gel-derived hybrid coatings provide excellent corrosion resistance and significant compatibility with traditional paint systems and, therefore, are a potential replacement coating for the Alodine layer. In addition, sol-gel-derived hybrid coatings are environmentally benign, providing a viable alternative to the traditional chromate-based surface pretreatment.

  The organic-inorganic coatings are prepared through the processing of alkoxide and organically-modified silane materials. The prepared coatings may be applied to metal substrates using various application methods, leading to the formation of a 5-15 micron thick, dense coating. In electrochemical and accelerated salt spray testing, sol-gel coatings exhibited excellent barrier protection properties and corrosion resistance characteristics among various aluminum alloys. Additionally, these coatings were found to provide good adhesion characteristics to both the aluminum alloy and also to organic polymer paint systems. Current research efforts are focusing on the preparation of sol-gel coatings containing inorganic filler and/or organic pigmented materials. Incorporation of inorganic filler materials was found to enhance the corrosion protective properties of the sol-gel coating. Several potential mechanisms are being investigated to explain this behavior, to include increased coating thickness and density. The incorporation of organic pigmented materials was found to aid in the preparation of highly colored hybrid coatings.

The Principal Investigators for this project include Tammy Metroke, PhD, Oklahoma State University Alan Apblett, PhD, Oklahoma State University

Source: website

Pollution Prevention Success Stories

HQ AFMC Funds Pollution Prevention Demonstration/Validation Projects to Meet High Priority Customer Requirements

AFMC takes a teaming approach in integrating weapon system HAZMAT reduction needs into the weapon system requirements generation, prioritization, funding, and execution processes. Generally, AFMC determines needs, develops a POM based on those needs, budgets for execution year, validates projects through the HQ AFMC P2-IPT, and, where possible, leverages resources to accomplish its goal.

On the weapon system pollution prevention continuum, HQ AFMC P2-IPT funds projects that fall in the technology integration, demonstration/validation to fielding category. HQ AFMC P2-IPT funds high priority projects that impact multiple weapon systems. HQ AFMC P2IPT also funds joint service projects, where the Air Force is a participant though the Joint Group on Pollution Prevention (JG-PP) and the Propulsion Environmental Working Group (PEWG). Where feasible, AFMC P2IPT favors technologies that are supported by other programs, such as the Strategic Environmental Research and Development Program (SERDP), and the Environmental Security Technology Certification Program (ESTCP).

Where feasible, AFMC P2IPT favors technologies that are supported by other programs, such as the Strategic Environmental Research and Development Program (SERDP), and the Environmental Security Technology Certification Program (ESTCP).

AFMC Air Logistics Centers (ALCs), test centers, research laboratories, and product centers often augment their pollution prevention program by seeking funds from HQ AFMC P2IPT for demonstration/validation efforts. Sharing of common solutions and prioritization of AFMC projects is conducting through the AFMC Center Working Group (www.hqafmc.wpafb.af.mil/p2ipt/index.html) and the Solutions Database (www.en.wpafb.af.mil/p2_solutions/p2_solutions.asp).

AFMC funds promising technologies for demonstration/validation through its pollution prevention narrative development (PPPN) process, discussed below. The top three success stories for AFMC funded projects include HVOF, powder coating, and handheld lasers (see pages 13-15). Currently, all three of these technologies are being successfully demonstrated/validated and/or transitioned to the ALCs.

Pollution Prevention Project Narrative Development (PPPN) Process

The Pollution Prevention Project Narrative (PPPN) process was developed by HQ AFMC to standardize the methodology for submitting and validating projects across the command. For weapon system pollution prevention projects, the HQ AFMC P2-IPT reviews AFMC submitted narratives for validity, feasibility, duplication of effort, and ensures the correct organizations are finding the solutions.

The top three success stories for AFMC funded projects include HVOF, powder coating, and handheld lasers. Currently, all three of these technologies are being successfully demonstrated/validate and/or transitioned to the ALCs.

HQ AFMC asks the product centers, installations, AFRL, LGP-EV, and other customers to annually submit PPPNs to the command by November of each year. HQ AFMC P2IPT reviews the submitted PPPNs and provides comments back the submitter by December in order to improve the quality of the narratives and provide additional details, as necessary. From December through January, the submitter revises the narratives and resubmits them back to HQ AFMC/CEVV for the HQ AFMC P2-IPT's initial review. In March of each year, all PPPN submitters attend a Proposal Review (PR) at AFMC, where they defend their projects. Based on the questions posed by the HQ AFMC P2-IPT and the Center Working Group members, the submitter provides final revisions to the PPPNs before the end of March. By April, the Validation Review Board makes its final determination of which PPPNs represent valid projects for the coming fiscal year

For further information about the HQ AFMC P2IPT funding process, please contact Mr. Ed Finke at DSN 757-6312 or at Edward.Finke@wpafb.af.mil.

ESTCP Project of the Year

Hard Chrome Plating Replacement with HVOF Thermal Spray Coatings on Landing Gear

"Chrome plating has been used for decades for application of wear-resistant, corrosion-resistant coatings in manufacturing operations. This plating uses hexavalent chromium, a known carcinogen. Accordingly, wastes generated from plating must be disposed of as a hazardous waste, and plating operations must abide by EPA emissions standards and OSHA permissible exposure limits. In addition to environmental and worker safety issues, limited wear and corrosion performance result in the chrome plate having to be stripped and re-applied during each overhaul cycle. To address this need, Mr. Bruce Sartwell (See Profile on page 22) of the Naval Research Laboratory has demonstrated that High Velocity Oxygen-Fuel (HVOF) thermal spray technology is an environmentally acceptable, cost-effective replacement for electrolytic hard chrome plating on aircraft landing gear and also improves wear and corrosion performance.

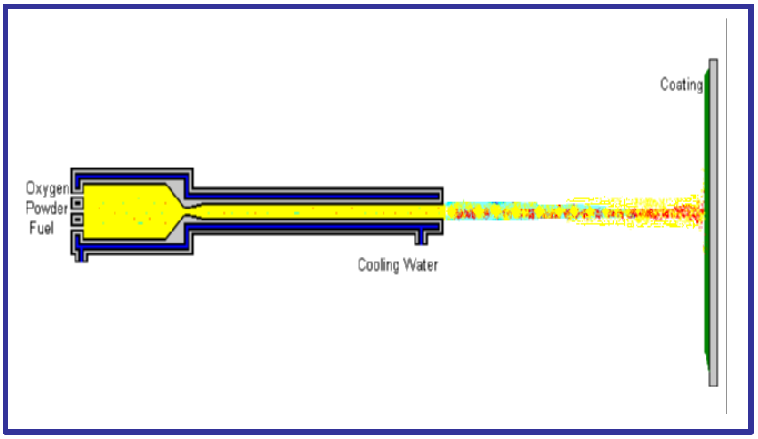
In 1998, landing gear project stakeholders were brought together to define the necessary materials testing required to qualify HVOF coatings as a replacement for hard chrome plating. Extensive fatigue, wear, corrosion, impact, and hydrogen embrittlement testing generally indicated that tungsten carbide cobalt applied with HVOF

Continued on Page 22

High Velocity Oxygen Fuel Thermal Spray Coating

Widest range of applications for replacing hard chrome coatings in aerospace military and commercial applications.

Overview



HVOF is a standard commercial thermal spray process in which a powder of the material to be sprayed is injected into a supersonic flame. The powder particles are accelerated to high speed and soften in the flame, forming a dense coating when they hit the substrate. The coating material is usually a metal or alloy (such as Tribaloy or stainless steel) or a cermet (such as cobalt-cemented tungsten carbide, WC-Co). Ceramic oxide coatings applied through the HVOF process are currently used to provide wear and corrosion resistance, as well as thermal protection in heat-sensitive applications. The technology is used to deposit coatings and to rebuild worn components.

Key Features

- Coatings are produced without overheating the substrate
- More uniform and efficient particle heating
- Lower surface oxidation due to shorter particle exposure

Key Benefits

- Superior in wear, fatigue, and impact resistance, and is usually equal or better in corrosion resistance
- Does not cause hydrogen embrittlement
- Faster deposition process, reduction in flow time

Applications

- Depots involved in repairing and overhauling landing gear, gas turbine engines, propeller hubs, hydraulic actuators, and helicopter rotating components

Known funding sources for development and transition of this technology include:
DARPA, ESTCP, and HQ AFMC P2IPT have all funded the successful transition of HVOF technology to the Air Force Air Logistics Centers (ALCs).

Technical Champion(s)
Bruce Sartwell (NRL) – Bruce.Sartwell@nrl.navy.mil
Keith Legg (Rowan Technology) - Klegg@rowantechnology.com
Johnny Tsiao (OC-ALC) johnny.tsiao@tinker.af.mil
Craig Edwards (OO-ALC) craig.edwards@hill.af.mil
James Hager (Warner Robins ALC) james.hager@robins.af.mil
AFMC POC - Warren Assink (HQ AFMC/LG) warren.assink@wpafb.af.mil

Websites
http://www.hcat.org
http://www.jgpp.com

Powder Coatings

Dry powder coating is one of the major advancements in paint application

Overview

Dry powder coatings that are commercially available include electrostatic dry-powder painting, fluidized bed method, and plasma spraying. In dry powder painting, a dry powder is metered into a compressed-air-driven spray gun and is sprayed at the prepared surface. An electrode in the spray gun ionizes the air and powder suspension using direct current, and the dry-powder particles then become charged. The surface to be coated is given the opposite charge, and the powder is electrostatically attracted to the surface. As the charged powder builds up, the coating thickness is controlled by the loss of attraction of the powder to the surface, resulting in a uniform thickness, even on complex shapes. The coating is then fused to the surface and cured in conventional ovens. Powder coating specifications used in AFMC include MIL-PRF-24712A.

Key Features

- Production improvements has driven the adoption of technology
- Shorter curing times increase production rates and complex shapes are evenly coated

Key Benefits

- For some applications, a single coating can replace multiple-coating applications used in conventional spray painting
- Enhance surface protection, better coverage, and reduced solvent emissions
- Powder coatings are Zero VOC and contain Zero HAPS

Applications

Applications being evaluated within AFMC include the following:

- Gear box (MIL-PRF-23377)
- Valves (MIL-PRF-23377, MIL-PRF-85285)
- Oxygen Bottles (MIL-P-1757, MIL-C-19573, MIL-C-19358)
- Containers (MIL-PRF-23377, MIL-PRF-85285)
- Life Raft CO2 Bottles (MIL-PRF-1757)
- Turbine (MIL-PRF-23377, MIL-PRF-85285)
- Powder coatings are in use on Flightline Fire extinguishers

Known funding sources for development and transition of this technology include: AFMC P2IPT

Technical Champion(s)

Steve Finley – Steven.Finley@wpafb.af.mil
Bernie Habib – Bernie.Habib@tinker.af.mil (OC-ALC)
Richard Buchi – Richard.Buchi@hill.af.mil (OO-ALC)
Dave Bury – Dave.Bury@robins.af.mil (WR-ALC)

Portable Handheld Lasers for Maintenance and Sustainment Applications

The wave of the future for supplemental paint stripping applications

Overview

Current methods for small area and supplemental coating removal of conventional and specialty coatings from on-equipment and off-equipment are costly, time consuming, labor-intensive, and result in undesirable environmental conditions. Laser technology is currently used in multiple manufacturing operations, including welding, cutting, drilling, and surface treatment and preparation. However, the use of laser energy for coating removal is a new technology that is environmentally acceptable and less labor intensive than current removal methods. Headquarters Air Force Materiel Command (HQ AFMC), as a part of the Joint Group for Pollution Prevention (JG-PP) program, and Air Force Research Laboratory (AFRL) is in the process of evaluating the use of handheld lasers for small area and supplemental coating removal for maintenance and sustainment applications. This evaluation includes testing and, if applicable, qualifying handheld yttrium aluminum garnet crystal doped with neodymium ions (Nd: YAG), transversely excited at atmospheric pressure-carbon dioxide (TEA-CO_2) and diode laser technology for removal of conventional and specialty coatings from metallic and composite substrates.

The Air Force (AF) has completed potential alternatives reports that investigated commercial off-the-shelf laser technologies, an initial cost benefit analysis analyzing the laser technology against the currently used baseline coating removal technologies, test plans that identify the requirements to demonstrate and validate the laser technologies, and safety and occupational health testing of the technologies. The AF is currently finishing testing of the laser systems to remove conventional coating systems from metallic panels. The AF is in progress of performing testing of composite panels with conventional and specialty coating systems and metallic panels with specialty coating systems.

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Pollution Prevention Success Stories at Oklahoma Air Logistics Center (OC-ALC)

OC-ALC manages an inventory of 2,267 aircraft including the B-1, B-2, B-52, C/KC-135, E-3, VC-25, VC-137, and 25 other Contractor Logistics Support aircraft. The Center also manages an inventory of more than 13,724 jet engines that range from the Korean Conflict vintage J-33 (T-33) to state of the art B-2 engines such as the F118. Missile systems managed by the Center include the Air Launched Cruise Missile, Short Range Attack Missile, Harpoon, and Advanced Cruise Missiles.

OC-ALC/EM has executed many successful pollution prevention projects over the years that have reduced cost and the ESOH burden. One of the key successes is the implementation of HVOF (see page 13). The electroplating of jet engine components at OC-ALC is being replaced with a robotically controlled HVOF metallic powder coating system. The new process provides a coating with wear and hardness qualities superior to those obtained from chrome plating. When fully implemented, the HVOF technology is expected to eliminate over 400 tons of RCRA-regulated waste, including 35 tons of hazardous chromium containing waste at Tinker AFB.

> *When fully implemented, the HVOF technology is expected to eliminate over 400 tons of RCRA-regulated waste, including 35 tons of hazardous chromium containing waste and waste chlorinated at Tinker AFB.*

Another pollution prevention success story at OC-ALC is the elimination of cadmium and nickel-cadmium tank electroplating. In 1991, OC-ALC replaced these processes with Ion Vapor Deposition of Aluminum (IVDAl). The introduction of IVDAl into the plating process, via a collaborative project between Tinker AFB and Boeing, has eliminated 50% of cadmium usage (195 pounds per year) in Tinker's Propulsion Directorate. IVDAl deposits a uniform coating of aluminum on the parts, has superior performance in comparison to cadmium, and has been successfully substituted on parts previously plated with cadmium and nickel-cadmium, such as tie rods and landing gear bolt pins. Before the elimination of cadmium tank plating, Tinker AFB used over 400 lbs. of cadmium per year. Today, only 40 lbs. per year are being used in small-scale brush plating operations. In addition, with the elimination of cadmium tank plating, cyanide products that are normally present in cadmium plating baths were eliminated.

> *Before the elimination of cadmium tank plating, Tinker AFB used over 400 lbs. of cadmium per year. Today, only 40 lbs. per year are being used in small-scale brush plating operations.*

Aircraft depainting is a vital step in the corrosion control and maintenance program at the OC-ALC. Historically, the primary method of depainting aircraft and aircraft parts has been chemical stripping, which poses hazards both to personnel and the environment. OC-ALC has replaced chemical stripping with a mechanical paint stripping alternative Aircraft Component Subsystem (ACS), which incorporates medium-pressure water and robotics, and reduces the use of hazardous chemical strippers. The ACS process has eliminated, on an annual basis, the use of approximately 140,000 lbs. of methylene chloride, 100,000 lbs. of hazardous waste, 76,000 lbs. of hazardous waste sludge at the Industrial Water Treatment Plant (IWTP), and 8.3 million gallons of wastewater. These reductions are anticipated to result in annual cost savings of $1.1 million dollars.

For additional information about pollution prevention success stories at Tinker AFB, please contact Bede Ley at DSN 336-5871 or visit the Solutions Database at https://www.en.wpafb.af.mil/p2_solutions/p2_solutions.asp.

Source: Pro-Act Fact Sheets

PEWG/JG-PP Qualifies Non-Lead Dry Film Lubricant for Anti-Seizing Applications

The PEWG is leading a joint DoD project to identify and qualify advanced dry film lubricants (DFLs) that do not use toxic materials, primarily lead compounds. DFLs are applied to threaded fasteners, compressor and turbine disks, and blade roots in aircraft engines to prevent seizing, galling, and fretting. Lead exposure is the primary environmental hazard targeted by this project. The PEWG in conjunction with the JG-PP, are working to define performance requirements for alternative DFLs and design a set of tests to validate the alternatives. The validation tests are documented in the Joint Test Protocol (JP-P-1-1) for Validation of Alternatives to Lead-Containing Dry Film Lubricants for Antigalling/Antifretting, Antiseizing, and Assembly Aid Applications, dated March 27, 2001.

Tiolube 614-T9B has been qualified for both low- and high-temperature antiseize applications. Everlube 812 is being tested for low-temperature galling/fretting applications. Everlube 10030 is being tested for high-temperature galling/fretting applications.

This project was divided into four phases to minimize the cost of qualifying alternatives. Nine candidate DFLs were down selected from an original list of 123 potential alternatives and tested for compliance beginning in Phase I. A Potential Alternatives Report (PAR) for Validation of Alternatives to Lead-Containing Dry Film Lubricants for Antigalling/Antifretting, Antiseizing, and Assembly Aid Applications, dated September 3, 1998, is available for review. Phase I and Phase II each eliminated 3 candidate alternatives. Three alternatives (Everlube 10030, Everlube 812, and Tiolube 614-T9B) successfully completed Phases I, II, and III testing, and are currently undergoing final testing in Phase IV. The test results for Phases I, II, and III are documented in an interim Joint Test Report (JTR) dated March 22, 2000. Phase IV testing is in-process. Tiolube 614-T9B has been qualified for both low- and high-temperature antiseize applications. Everlube 812 is being tested for low-temperature galling/fretting applications. Everlube 10030 is being tested for high-temperature galling/fretting applications. Phase IV testing is in progress with the Final Test Report to be delivered in July 2004. Since starting this project, the participants have identified the need for a DFL in paste form to be used during the GTE repair and overhaul process. The PEWG is also working with the F-16 System Program Office at Wright-Patterson AFB to explore uses other than on gas turbine engines.

For further information, please contact Ms. Mary Swinford at DSN 785-4169, ext. 3185.

This article was submitted by Ms. Penny Kretchmer, PEWG. When fully validated, the solutions from this effort will be implemented at OC-ALC.

POLLUTION PREVENTION SUCCESS STORIES AT OGDEN AIR LOGISTICS CENTER (OO-ALC)

Ogden Air Logistics Center (OO-ALC) overhauls and repairs landing gear, wheels and brakes, rocket motors, air munitions and guided bombs, photonics equipment, training devices, avionics, instruments, hydraulics, software and other aerospace related components. OO-ALC provides worldwide engineering and logistics management for the F-16 Fighting Falcon jet aircraft, and is the depot-level maintenance center for F-16 and C-130 Hercules aircraft. Highly trained personnel at Hill AFB also conduct logistical management for the nation's fleet of strategic ICBMs.

The implementation of the Laser Automated Decoating System (LADS) for stripping F-16 radomes is one of the major pollution prevention success stories at Hill AFB. Typically, an F-16 radome will be repainted and recalibrated several times during its lifetime. Conventional abrasive and chemical stripping depainting processes can damage surfaces and shorten the life of the radome. Within the nation's fleet of several hundred F-16s, approximately 48 out of 150 radomes depainted must be replaced each year due to the damaging effects of manual paint stripping processes. A radome costs approximately $41,000 to replace. This loss amounts to an annual cost of nearly $1.9 million. The manual stripping of a radome consumes 8-16 labor-hours, 7-31 days, and generates over 300 gallons of hazardous waste. In addition, there are many safety and occupational health hazards associated with this process. The cost associated with radome depainting, painting, and recalibration can easily approach the replacement cost. The LADS can be configured to depaint a variety of aircraft and AGE components. The depainting cost with the LADS method is only $4,000 per radome. In the three years it has been in operation, the LADS has saved the Air Force over $500,000 per year in radome replacement costs, and another $125,000 per year in hazardous waste disposal costs. Hill AFB plans to have LADS depaint more F-16 radomes as well as C-130 radomes and wing components, which is expected to generate significant additional cost savings.

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HVOF (see page 13) has been implemented at Hill AFB because of the reduction in flow time. HVOF has reduced the plating process from five days to one day because the use of robotics makes the application more precise, resulting in less re-work. Hill AFB has one fully operational cell and is constructing on a second cell. Hill AFB has already transitioned parts that have chrome in the line of sight to HVOF. Full transition is anticipated to be completed in the next two to three years.

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Implementation of X-It Prekote as an alternative to chrome conversion coating has been another major success. The conversion for alodine to X-it Prekote has resulted in a savings of $1,600 per F-16 aircraft, which translates into an annual savings of $320,000. Hill AFB is working with the C-130 SPO to qualify the product on the weapon system. This alternative is applicable AF wide.

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Under the Have Glass Program for the F-16, PRC DeSoto's Product 513X423C was qualified for use on the F-16 at Hill AFB. Flight-testing and approval of use of 513X423C through a TO change has been completed and the new primer is used on 399 Block 40 F-16 Aircraft at Hill AFB**.** The success of this project was highly dependent on the collaboration between the System Program Office, the Original Equipment Manufacturer, the Coatings Technology Integration Office, and Hill AFB. Leveraging existing data and then conducting additional testing at Hill AFB was critical to obtain Single Manager buy-in and the subsequent TO change. Additionally, the use of the primer had directly significance to production. Paint primer defect rate went down to zero and the performance was as good as the use of a high VOC Primer.

For further information regarding these pollution prevention success stories, please contact Richard Buchi at DSN 775-2993 or visit the Solutions Database website at https://www.en.wpafb.af.mil/p2_solutions/p2_solutions.asp.

Sources: AF PA and Pro-Act Fact Sheets

Cross Into Pretreatment

The U.S. Air Force has examined non-chromate conversion coatings in an effort to find a product that is environmentally favorable and provides excellent corrosion resistance. Crews at Hill AFB conducted tests on several non-chromate conversion coatings in an effort to eliminate and reduce chromate compounds in the paint preparation process for aircraft.

Initially crews had been using VOC compliant primers and high solid paints on aircraft, however they found that these paints did not adhere to the aircraft. As a result of these findings, the study on non-chromate conversion coatings was initiated. Nine tests were conducted to evaluate the products and included the following: Uniform Color, Bonding in the Presence of Known Contaminants, Corrosion Resistance, Ease of Application, Hydrogen Embrittlement, Kapton Wire testing, Adhesion testing, Flexibility, and Surface Analysis.

A total of four non-chromate conversion coatings were tested. Representatives of the product's company properly prepared the initial coatings, and testing eventually was conducted. PreKote was the final conversion coating chosen by Hill AFB. After the non-chromate conversion coating was chosen, Hill AFB fully prepared the right wings of two F-16's with PreKote, and the remainder with chromate conversion coatings.

It has been determined that the new process resulted in positive results. Final cost-benefit findings came in three aspects. First the new process eliminated hazardous waste while reducing the costs of disposal costs. Second, it has helped the Air Force to require less time to prepare and paint the aircraft. Third, the process also helped reduce labor by 35%, saving $1,600 per plane.

Graves, Beverly A. 2003. Cross Into Chrome Free Pretreatment. Available at *http://www.pfonline.com/articles/010302.html* ⬣

Pollution Prevention Success Stories at Warner Robins Air Logistics Center (WR-ALC)

Warner Robins Air Logistics Center (WR-ALC) provides management and engineering responsibility for the repair, modification and overhaul of the F-15 Eagle, the C-130 Hercules, the C-5 Galaxy, and all Air Force helicopters. The Center also provides logistical support for the C-17 Globemaster III, all Air Force missiles, vehicles, general-purpose computers, as well as avionics and electronic systems on most aircraft. Robins is home to more than 62 hosted organizations, including the Air Force Reserve Command, the 116th Air Control Wing and its E-8C Joint Surveillance Targeting and Attack Radar System aircraft, the 5th Combat Communications Group, the 19th Refueling Group and its KC-135R Stratotankers.

WR-ALC/EM and WR-ALC/MAPE have executed many successful pollution prevention projects over the years that have reduced cost and the ESOH burden. Implementation of Flashjet is a major pollution prevention success story at Robins AFB. The Flashjet operation at WR-ALC is the first in the Air Force; however, in April 2001, the applicable Technical Orders were changed to reflect its approval for Air Force-wide use. The Flashjet workload is estimated to be approximately 250 radomes and 1,000 parts processed through the facility per year. Flashjet is projected to save over $900,000 annually, reduce methylene chloride use by approximately 22,000-gallons, and methyl ethyl ketone (MEK) use by 2,000-

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gallons. This process lessens damage to the composite substrate surfaces, extending the life of aircraft radomes and composite parts. Previously, these parts were stripped using methylene chloride-based paint removers. Residual coatings were removed with MEK. A specialized C-130 radome was stripped by hand sanding, which could take up to two weeks and increased the risk of damage to the substrate material.

WR-ALC/MAPE is also participating in the JG-PP handheld lasers for small area depaint project (see page 15). Handheld lasers will complement the Center's existing paint stripping processes, including Flashjet.

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A process change using Plastic Media Blast (PMB) in lieu of chemicals to depaint aircraft parts is projected to reduce the use of methylene chloride by 200,000-pounds, and hazardous waste disposal by 145,000-pounds per year. The list of candidate parts for this process spans all weapon systems serviced at the Center, from wings and landing gear doors to fuel tanks. The use of PMB is a closed loop process that entails leasing the PMB, with waste material returned to the provider for use in the manufacture of new products such as concrete blocks. The newly manufactured products are then returned to the marketplace

WR-ALC/MAPE is also currently developing a selective stripping technology that involves a barrier coat system. The system consists of a chromated primer applied over bare substrate (current method), a barrier coat, and a topcoat. The significant difference between the barrier coating system and the current coating system is seen when the aircraft requires depainting. With the barrier coat in-place, only the topcoat is stripped using either medium pressure water (8,000 to 10,000 psi) or dry media that does not remove or damage the barrier coat or primer coat. This selective stripping system leaves the barrier coat and primer coat in-place; thereby dramatically reducing the usage of chromate conversion coating (alodine) and the chromated primer coating. Generation of chrome-containing waste is essentially eliminated, plus, the water or dry media used in the depainting process can be recycled. Aside from the environmental benefits and cost savings

Implementation of a barrier coating is projected to save $22 million per year and reduce worker exposure to hazardous materials by 97%.

that result from the reduction in man-hours for depaint and paint processes, there is an additional benefit for employees who will no longer be exposed to chromate during depainting. Currently, flight-testing is being conducted on three military aircraft (two F-15 & one C-130), with two more in the testing phase. Implementation of a barrier coating is projected to save $22 million per year and reduce worker exposure to hazardous materials by 97%.

Another success story is the substitution of HFE-71DE (hydrofluoroether azeotrope) for CFC-113 in the gyroscope facility. HFE-71DE, demonstrated and validated through the Toxic Release Inventory Alternative Development (TRIAD) process, resulted in a 99.9% reduction in the use of CFC-113, from approximately 5,000-pounds per year to just 1-pound per year.

WR-ALC has designed and commercially built a vacuum waste collection system, based on the results of a process specific opportunity assessment (PSOA), to manage flight line vacuum waste that is generated at various locations associated with aircraft maintenance. Prior to the process change, wastes was collected in vacuum units which, when filled, were transported to a centralized location where they were manually drained, cleaned, and the waste transferred to drums for disposal as hazardous waste. The former waste collection process generated approximately 250,000-pounds of waste per year at a disposal cost of $204,000. Based on documented results, the new process generates only 168,000-pounds of waste per year at a disposal cost of only $97,000. This new system automatically separates the water from the oil via a sensor placed in the vacuum unit. It sends the water directly to the industrial wastewater treatment plant via a connection to the underground pipeline collection system, and only the waste oil is pumped into drums for disposal as hazardous waste.

For further information about these success stories, please contact Mr. Dave Bury at DSN 468-1197 ext. 114 or visit the Solutions Database web site at https://www.en.wpafb.af.mil/p2_solutions/p2_solutions.asp

Source: Pro-Act Fact Sheet

ESTCP Project of the Year

Continued from Page 12

had superior performance over hard chrome. The Navy has recently and successfully conducted component rig testing on F-18 E/F nose landing gear and the P3 main landing gear.

The results of a cost/benefit analysis using HVOF versus chrome plating at one landing gear repair facility concluded that an annual cost avoidance at that facility alone was approximately $200,000, and the 15-year net present value was close to $2 million. These recent successes are leading to the installation of numerous HVOF systems at the three Air Force logistics centers and at the Navy's Jacksonville and Cherry Point air depots. Most encouraging is that HVOF coatings are being designed into the newest aircraft entering the fleet such as the Joint Strike Fighter as well as commercial aircraft such as the new Airbus A380."

Source: www.serdp.org/symposiums/2003/abstracts/Sartwell_abstract.pdf

Profile: Bruce Sartwell (Hard Chrome Alternatives Team)

Bruce Sartwell serves as the Program Manager for the ESTCP and SERDP HCAT related projects and is located at the Naval Research Laboratory, Washington, DC. Mr. Sartwell holds Bachelor of Science Degree in Physics and a Master of Science Degree in Materials Engineering.

His responsibilities have included coordinating hard-chrome-plating replacement projects with the DoD Joint Group on Pollution Prevention (JG-PP) and Propulsion Environmental Working Group (PEWG), which involved development and execution of Joint Test Protocols for qualifying thermal spray coatings as replacement technology.

Mr. Sartwell has received the ESTCP Project of the Year in 2003 with Mr. Keith Legg for Hard Chrome Plating Replacement with HVOF on Landing Gear.

Please visit the HCAT website at http://www.hcat.org for more information about this team.

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Key Features

- Highly portable, maneuverable, and suited for small spaces.
- Relatively low cost.
- Adaptable for glove box design.
- Maximum power ranges from 40 – 500W.
- Laser delivered through umbilical arm or fiber optical cables. Fiber optic delivery of the Nd:YAG and diode laser increases the flexibility of beam delivery in work areas where space and movement are premium.

Key Benefits

- Reduces/minimizes the need for conventional supplemental stripping (e.g. use of methylene chloride).
- Controllable paint removal process.

Applications

- Supplement the removal of conventional and specialty coatings from steel, aluminum, and composites from various aircraft. The coatings and substrates undergoing testing include:

Coatings		
MIL-P-23377 primer	MIL-PRF-85582 topcoat	Low Observable Material (MS-170)
MIL-C-5541E primer	MIL-PRF-85285 Type I, topcoat	Fastener Fillers (Flex Fair 9794)
MIL-P-53030 primer	Advance Performance Coatings	Polysulfide Sealants (PR1440-B2)
10PW 22-2 primer	MIL-C-46168, Type IV, topcoat	Gap Filler (PR2200)
PR1432GP primer	CARC MIL-C-64159, Type I,	Bond-o (EA9394)
Super Koropon 515-K01A primer	Radar Absorbing Material (RAM) (spray and sheet)	Epoxy Powder Coating
Substrates		
2024-T3 Aluminum	Kevlar	Bismaleimide (BMI) composite
7075-T6 Aluminum	Fiberglass/epoxy composite	Polyetheretherketone (PEEK)
4130 Steel	Metallic (Al) honeycomb	

Known funding sources for development and transition of this technology include:
AFRL, ESTCP, AFMC P2IPT

Technical Champion(s)

HQ AFMC
Debora Meredith – debora.meredith@wpafb.af.mil
Gerard Mongelli (*CTC*[1]) – gerard.mongelli@wpafb.af.mil

AFRL
Thomas Naguy – thomas.naguy@wpafb.af.mil
Randall Straw (*CTC*) – randall.straw@wpafb.af.mil

Support Contractor
Stefan Susta – stefan.susta@saic.com
Georgette Kotsagrelos – kotsagre@ctcgsc.org

Website

http://www.jgpp.com

This article was prepared by the AFMC Laser Team.


15 – 17 March 2004
Embassy Suites Hotel Las Vegas
Las Vegas, Nevada USA
Aeronautical Systems Center
Air Force Research Laboratory
2004 Air Force Deicing Conference
Aircraft and Runway Deicing/Anti-Icing
This event will focus on lessons learned and operational requirements that lead to material solutions, changes to applicable Technical Orders and Air Force Instructions, as well as, provide briefings on new technologies, policy updates, and the AF Pollution Prevention deicing technology roadmap.
For additional program and registration information, visit:
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Tels. (937) 255-6526, 656-6178 E-mail: alexei.lozada-ruiz@wpafb.af.mil